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Life cycle assessment of biogas production at the research plant Unterer Lindenhof of the Universität Hohenheim

Significant contributions to anthropogenic greenhouse gas emissions are caused by agricultural activities. An effective way to reduce agricultural emissions is the implementation of liquid manure to produce biogas, whereby the greenhouse gas emissions from manure storage are avoided. Additionally, renewable energy in terms of heat and electricity is generated in combined heat and power plants which substitute fossil power plants. The objective of this study was to assess the environmental impacts of biogas production at a research plant of the University of Hohenheim. A model was designed to evaluate the biogas production systems according to their environmental impact using Gabi 4.3 software. Besides global warming potential other impact categories have been used to evaluate the systems effects in the field of eutrophication and acidification. The results show that environmental benefits can be obtained with regard to the emission of greenhouse gases when comparing electricity production from biogas.

Keywords
Life cycle assessment, LCA, biogas

Abstract
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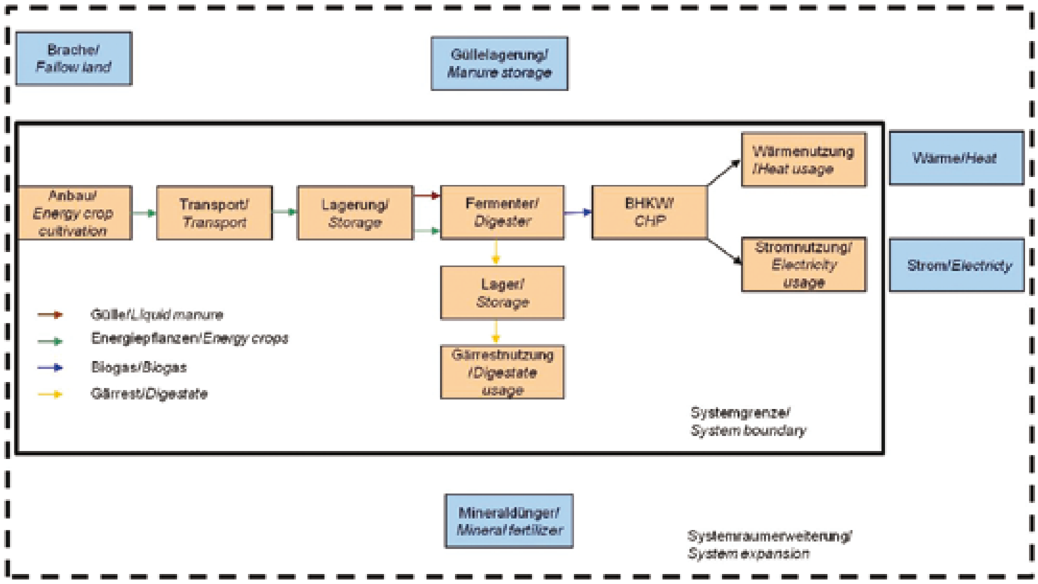
Concerning Germany the Federal Environment Agency [1] states that from 2003–2007 the annual emission of CH_4 related with manure management accounted for 260 000 tons of overall agricultural Greenhouse Gas (GHG) emissions (UBA 2009a). Emissions from manure storage can be avoided when using the manure as an input substrate for anaerobic digestion. When the produced biogas is used in a Combined Heat and Power Plant (CHP) for generation of electricity and heat, emissions from conventional production systems are avoided by substitution. This study uses the method of Life Cycle Assessment (LCA) to illustrate in which amount biogas production can contribute to a reduction of environmental impacts under German conditions. At this juncture, biogas production at the research plant of the Universität Hohenheim at Unterer Lindenhof serves as an example.

Material und Methods

The study is methodologically based on the international standards for life cycle assessment [2, 3] according to the latest version. Aim of the research was to assess the environmental impacts of biogas production at the biogas plant of the research facility. Chosen as the Functional Unit (FU) was the production of a quantity of biogas with a calorific value of 1 MJ. System boundaries encompass the supply of the energy crops, usage of biogas digestate as a fertilizer and also heat and electricity production in a CHP. The time frame is 12 months in 2009. Site specific data was used wherever available and added with information from EcoInvent-database [4]. The production of crop whole plant silage was adopted from a model by Stenull and Eltrop [5]. System expansion was used to deal with (by-) products of the system based on [3] to avoid allocation. Statistical data provided by the Federal Ministry of Food, Agriculture and Consumer Protection names the most important domestic sales regarding mineral fertilizers in Germany in the business year 2007/08 [6]. When considering straight fertilizers these are: calcium ammonium nitrate for N, super phosphate for P_2O_5 and potassium chloride for K_2O. Therefore the assumption in this study is that the plant available part of the nutrients in the

Fig. 1



Production system with system boundaries and system expansion

biogas digestate replaces these mineral fertilizers and is credited. Supposed to be plant available is a share of 80 % for N and 100 % for P_2O_5 and K_2O [7, 8]. The part of digestate which is residue from manure digestion is used for fodder production and hence is excluded from this credit. Field emissions from biogas digestate are calculated as 30 % of NH_4-N as NH_3 based on [9, 10] and 1 % of remaining N as N_2O [11], while diffuse CH_4-emissions from the digester are assumed to be 1%. At the research farm where the biogas plant is located a natural gas burner and a mineral oil burner were used for generating heat before the CHP with an electrical power of 186 kW was installed. Because no operating data from the oil burner was available it was assumed in this study that CHP-heat substitutes heat from a gas burner. The electrical power generated is fed to the national electricity grid. The electricity requirement of the biogas plant was calculated with 8.8 % of the total electricity produced [12], heat requirement with 16.8 % of heat produced, both based on measurements at the research facility. The dry matter and organic dry matter content of the feedstock was included on the basis of weekly analyzes [13]. An overview of the system under research and the reference systems is given in **figure 1**.

The input substrates used in the digesters are liquid manure, solid manure, maize silage, grass silage and grain with a total annual input of 7 155 t. Based on on-site measurements the emissions factors for the CHP were calculated [14]. These factors and the mass input of the single input-substrates are shown in **table 1**.

The method for impact assessment used was CML 2001 as released in 2007. The impact assessment categories described in this paper are Global Warming Potential (GWP), Acidification Potential (AP) and Eutrophication Potential (EP).

Table 1

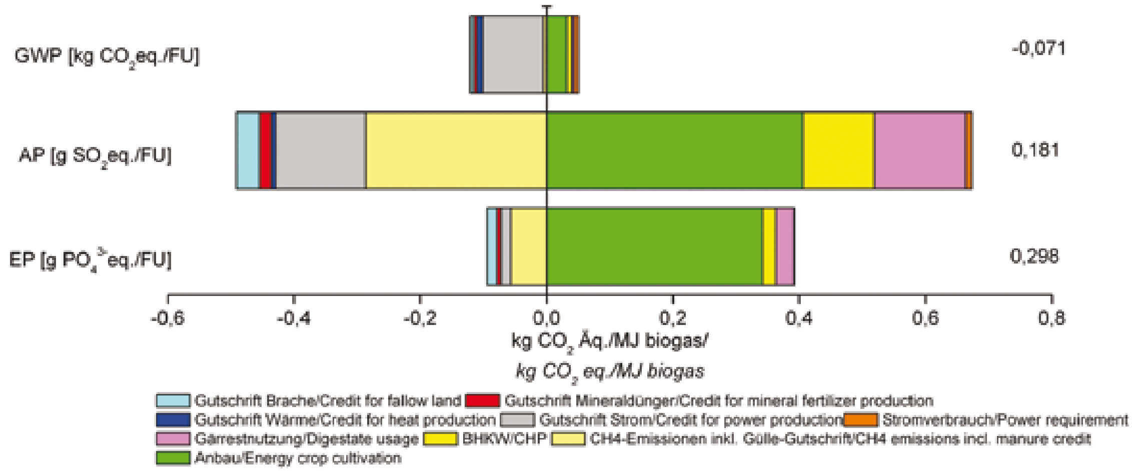
Mass of the feedstock and emission factors of the CHP

Parameter *Parameter*	**Einheit** *Unit*	**Wert** *Value*
Ausgangsstoffe/*Feedstock*		
Flüssigmist *Liquid manure*	t/a	4 100
Festmist *Solid manure*	t/a	849
Maissilage *Maize ensilage*	t/a	965
Grassilage *Gras ensilage*	t/a	411
Getreide und GPS *Grain*	t/a	601
Gesamt *Total*	t/a	6 926
Emissionsraten BHKW/*Emission rate CHP*		
CH_4	g/h	563
SO_2	g/h	1,97
NO_x	g/h	281
CO	g/h	452

Results

The results show that GHG emissions can be reduced when using agricultural manures (liquid and solid) as an input substrate for anaerobic digestion with additional usage of biogas in a CHP, the final products being heat and electricity (**figure 2**).

Fig. 2



Global warming potential (GWP), acidification potential (AP) and eutrophication potential (EP) of the biogas production at the research plant

The amount of GHG savings related with biogas production at research plant is 71 g CO_2-equivalents/MJ biogas. Emission credits as well as burdens contribute to the final result. The highest credit concerning GHG emissions was 96.2 g CO_2-equivalents/MJ biogas due to the replacement of traditional fossil fuel power plants by biogas power plants. Furthermore, a significant GHG reduction can be related to the utilization of CHP heat (8.9 g CO_2-equivalents/MJ biogas) and the replacement of mineral fertilizers (4.9 g CO_2-equivalents/MJ biogas).

Regarding other environmental impacts the results differ from GWP. Both EP and AP values have increased with biogas production. The main credits correlated with AP and EP were given for the avoided manure storage and marginal power production. Besides crop production, digestate usage and the operation of the CHP causes considerable emissions.

An important difference in the total CH4 emission of the CHP results from the emission factor used. There is a wide spread in literature that ranges from about 0.5 to 3.74 % of CH_4-production of the biogas plant for methane slip [15]. In the LCA of this study CH_4-emissions from CHP were calculated with 1.58 % based on on-side measurements [14]. This results in a total annual CH_4 emission of 93.1 t CO_2-equivalents at CHP. Calculated with literature values instead of measured data the emission ranges from 26.4 to 220 t CO_2-equivalents. Obviously there is a nameable uncertainty included in the GHG emission when calculated with literature values instead of measured ones.

Conclusion

The research demonstrates that anaerobic digestion is a practicable solution for the reduction of greenhouse gases related with manure management. Furthermore, the generation of electricity from biogas in a combined heat and power plant is advantageous when compared with electricity generation in conventional power plants. To avoid CH_4-emissions from CHP and thereby reduce the GWP, it is necessary to adjust the CHP regularly to a low CH_4 slip during maintenance. Uncertainties which are caused by processing a LCA of biogas production with secondary data can be reduced by the usage of measured data. This allows a more precise calculation of the reduction of GWP.

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